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Mars Global Surveyor Mission

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ABSTRACT

The development of a new mission to observe Mars from orbit is underway by the National Aeronautics and Space Administration and the Jet Propulsion Laboratory. This mission, the Mars Global Surveyor, will be launched in late 1996, and is the first mission of the new Mars Surveyor Program, a program with international participation, that will characterize the planet Mars from orbital observations and from surface measurements.

This paper discusses the technical and programmatic considerations which have been combined to formulate the plans for the Mars Global Surveyor (MGS).

The first objective of the mission is to complete, as fully as possible, the five original science objectives of the failed Mars Observer mission. The MGS spacecraft, which will accommodate part of the Mars Observer instrument payload, will focus on surface science to provide the data base for landed missions that will follow in the Mars Surveyor Program in later years. Secondly, the spacecraft will provide a one-way relay capability for US and international landed and atmospheric missions. Thirdly, the mission will provide special emphasis on those measurements which could impact landing site selection.

The performance requirements for the MGS spacecraft will be discussed and the payload will be described. The status of the project development at launch minus 13 months will be highlighted.

The implementation of this mission will be affordable, engaging to the public and provide numerous public educational benefits. Its management will be cost, rather than performance, driven. Low cost mission operations will be incorporated.

The programmatic approach and plans will be described.

Finally, lessons learned from the Mars Observer experience will be shown to provide enhancements to the affordability and success of the Mars Global Surveyor Mission.

INTRODUCTION

The Mars Global Surveyor (MGS) mission is an outgrowth of the failure of the Mars Observer spacecraft in August 1993. It is the first mission of a series of robotic missions to Mars planned by the National Aeronautics and Space Administration over the period of the next decade to be executed by the Jet Propulsion Laboratory.

With the demise of Mars Observer (MO), and pending reductions in expenditures for planetary exploration, NASA was essentially without a viable program of exploration of Mars. Members of the scientific community called for some means of recapturing the objectives of Mars Observer as rapidly as possible.

The Mars Global Surveyor mission was planned and included in the NASA budget during the period between September 1993 and February 1994, the fastest a planetary mission has ever been conceived. The mission was subsequently approved by the US Congress for new funding starting in October 1994 for a launch in November 1996.

SURVEYOR PROGRAM

Mars Global Surveyor is the first mission of a decade long program of Mars exploration termed the Mars Surveyor Program. It consists of missions to Mars at every opportunity beginning in 1996, with orbiters and landers. The program provides the technical and operations experience, and the scientific database to

enable a sample return mission in the following decade and for eventual human exploration of Mars,

The Surveyor Program is planned with funding levels of approximately \$100M per year to include mission, spacecraft development, and flight operations. Orbiters will provide data acquisition on a global scale over the period of a full Martian year, and landed elements will provide for local, focused science. Orbital missions will also provide relay communication for the landed elements. For other than the first mission, the Surveyor program is characterized by the launch of two missions each Mars opportunity (approximately every 26 months), and by the constraint to use the Med-Lite launch vehicle.

The first mission in the program, MGS, is assigned to fulfill as many of the scientific objectives of the lost Mars Observer mission as can be accomplished within its programmatic constraints. It is constrained to use the Delta II launch vehicle.

MGS PROGRAMMATIC CONCEPT

The challenge of MGS is to develop a mission ready to launch in 26 months within a cost cap of \$154M. This required extraordinary technical and management approaches characteristic of the faster-better-cheaper concepts that are driving NASA today.

JPL had a vast experience base from the Mars Observer mission. It had just flown the MO spacecraft for 10 months, and had completed 8 years of MO spacecraft, mission, and science development. It had a technical and management team that was very motivated to recover from the loss of MC. In addition, it had a complete set of spare hardware for the MO spacecraft and some spare elements of the science payload.

Studies conducted by 13 industrial contractors during the fall of 1993, along with JPL's team, concluded that missions were feasible with various parts of the MC science instrument payload and could be implemented within the programmatic constraints applied in time to meet the November 1996 launch date.

A competitive selection process resulted in the selection in July 1994 of Lockheed Martin Astronautics (LMA) of Denver, Colorado, as the industrial partner in the MGS project with the

responsibility of designing, building and testing the MGS spacecraft. LMA proposed a spacecraft built from the spare electronic assemblies of MO with a new composite material structure and a new dual mode propulsion system.

JPL is the project manager, does the mission design, and manages the flight operations. The science payload was selected by NASA Headquarters as a subset of the MO payload. The instruments are implemented by the selected Principal Investigators.

The programmatic concept for MGS was to use as much as possible of the mission design, science instruments, flight operations design and ground data system inherited from MO. This turned out to be quite feasible, although two significant changes were required to meet the programmatic constraints. First, aerobraking at Mars is required because the mass limitation imposed by the injection capability of the prescribed launch vehicle would not allow enough on-board fuel to be carried to achieve the required mapping orbit at Mars. Second, the size of the flight operation team had to be reduced to fit fiscal constraints.

Because of the fiscal limitation of \$154M for development cost (to launch plus 30 days), the project adopted a cost driven paradigm wherein cost growth above the limit would be eliminated by the reduction of performance capabilities within the mission. "To support the maintenance of the cost cap, the project introduced critical path schedule performance assessment and earned value monitoring, as well as a set of metrics that provide early indication of programmatic and technical performance.

The establishment of a sharing of responsibilities relationship with the industrial partner is the another key concept of this fast track project. JPL brought \$30M worth of spacecraft hardware and perhaps \$80M worth of sunk engineering design to the partnership. LMA brought propulsion, structure, spacecraft integration and test capabilities to the partnership. In addition, flight operations will be shared with LMA, wherein LMA provides the spacecraft health and welfare function, and JPL provides the mission sequence plan. Electronic interfaces have been established between JPL in Pasadena, California, and LMA in Denver, Colorado. The project uses electronic documentation and has established paperless processes for project development and flight operations.

MISSION DESCRIPTION

The MGS mission is designed to perform an intensive study of Mars' atmosphere, surface and interior over the period of a Martian year (687 days). Five major experiments and six interdisciplinary investigations will be undertaken. The payload consists of five instruments and the spacecraft telecommunication system. Following the initial two years of mapping the spacecraft will serve as a radio relay station for data from sulfate experiments of the US and other nations for an additional three year period. The timeline for the mission is shown in Figure 1. Mission characteristics are listed in Table I and key events are shown in Table II.

The mission's payload will be delivered to Mars on a spacecraft bus launched in the November 1996 Mars opportunity by a McDonnell Douglas Delta II 7925 vehicle from the Cape Canaveral Air Force Station. After a ten month cruise to Mars, the spacecraft will be inserted into Mars orbit by a chemical bi-propellant system. During the next five months, aerobraking techniques will be used to transform the initial elliptical 48 hour orbit into a circular sun synchronous (at 2 PM) 2 hour orbit from which the mission's experiments will be performed and the planet mapped.

Aerobraking is a key feature of the MGS. It is required because the injection capability of the Delta II is not sufficient to launch the mass of fuel required to use chemical propulsion to establish the required circular orbit for mapping. Aerobraking was first used in a planetary mission by the Magellan spacecraft at Venus in 1993 as a demonstration experiment following the completion of the Magellan's prime mapping mission. Aerobraking will be used for the first time on a planetary mission on MGS as a prime function in accomplishing the mission's objectives. Aerobraking is accomplished by repeatedly dipping the spacecraft into the top of the Martian atmosphere at each periapsis passage, slowing its orbital speed and thus lowering the apoapsis in order to circularize the orbit.

The mapping orbit will be sun synchronous with its descending node at the 2 PM fictitious mean sun position in order to provide the same lighting conditions for all data acquisition. The orbit will have an index altitude of 378 km, an inclination of 92.9°, and a period of 117.65 minutes. The orbital

path nearly retraces the ground track every seven Martian days (88 orbits), with a 59 km eastward offset from the previous cycle. The cycle repeats after 26 Martian days (327 orbits). This process enables the instruments to observe over 99% of the planet's surface. The characteristics of this orbit were selected to complement the characteristics of the payload instruments.

Another key feature of the MGS mission is that data is acquired continuously from the payload instruments, stored on-board for transmission to Earth once each day during one tracking pass of a 34m Deep Space Network station. An additional pass once every three days allows the transmission of real-time data to augment the continuous mapping data with special targeted observations, such as high resolution imaging.

The orbital mission design, with the exception of aerobraking, is nearly identical to that previously planned for the lost Mars Observer mission. MGS carries all but two (Gamma Ray Spectrometer, and Pressure Modulator Infrared Radiometer) of the Mars Observer science payload instruments.

TABLE I: MISSION CHARACTERISTICS

Launch period:	November 5-25, 1996
Arrival period:	September 11-22, 1998
Launch Vehicle:	Delta II (7925)
Initial Mars Orbit:	
period:	48 hours
periapsis altitude:	314 km
highly elliptical	
Mapping Orbit	
period:	117.65 minutes
index altitude:	378 km
sun synchronous:	2 PM
inclination:	92.9°
nearly circular	
Mapping period:	687 Earth days
Relay period:	approximately 3 Earth years
Velocity Change Budget:	1290 m/s (95% confidence) total (includes MOI at 981.5 m/s)
Tracking requirements:	1- 10 hours pass with a 34m station each day for stored data playback and navigation; 1 additional 34m station pass every third day for real-time data;

Figure 1: MGS Mission Timeline

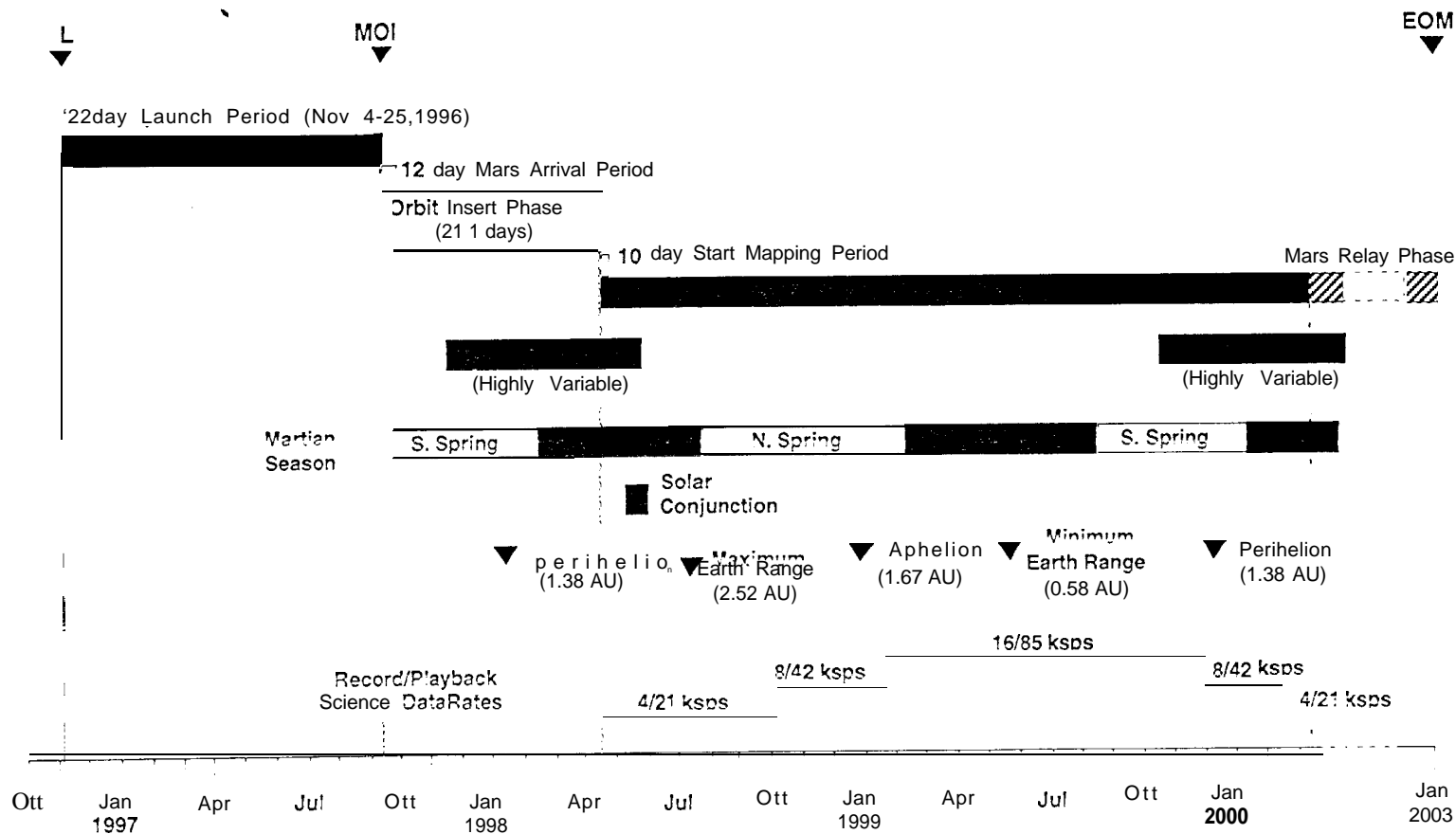


TABLE II: KEY MISSION EVENTS

Launch:	November 5, 1996
Inner Cruise:	Nov. 5, 1996 to Jan 4, 1997
TCM 1:	Nov. 20, 1996 (1+ 15 days)
Outer Cruise:	Jan 4, 1997 to Sept.10, 1997
TCM 2:	Mar 20, 1997 (1+135 days)
TCM 3:	Apr. 19, 1997 (1+165 days)
TCM 4:	Aug. 22, 1997 (MOI-20 days)
Mars Orbit Insertion(MOI):	Sept.11, 1997
Aerobraking:	Sept. 11, 1997 to Mar 11, 1998
Mapping:	Mar 15, 1998 to Jan 31, 2000
Relay Phase:	Feb. 1, 2000 to Jan 1, 2003

The mission sequence is characterized by five phases which encompass events that perform certain enabling functions for the mission.

The launch phase includes the Delta II countdown to separation of the spacecraft from the Delta's (bird stage). The launch period extends for 21 days from November 5 to November 25, 1996. This period was chosen to provide the required injection energy, and to provide enough time to assure a high probability of accomplishing the launch given conflicts on the Air Force missile range, unacceptable weather, spacecraft and/or launch vehicle anomalies. Two launch azimuth opportunities will be utilized for each of the first 11 days of the period so as to maximize the probability of launch during this period which results in the minimization of the aerodynamic heating uncertainty during aerobraking. Historical data combined with the use of two azimuths per day shows that the probability of launching in the first 3 days is 96%. The first and second stages of the Delta II vehicle put the spacecraft and the third stage, a PAM-1, in an Earth parking orbit. The PAM-1 injects the spacecraft into the trans-Mars orbit.

The cruise phase is nearly ten months in duration covering the time from the spacecraft's separation from the launch vehicle to Mars orbit insertion (MOI). It includes the deployment of the solar arrays and the initial in-flight checkout of the spacecraft systems and the science payload. Communications during the first four months, called inner cruise, is via the spacecraft's low gain antenna because the undeployed high gain antenna does not point in the earth direction during this period. The first trajectory correction maneuver, which is designed to remove launch errors and biases, is performed 15 days after

launch. In the latter part of cruise, called outer cruise, when the sun-spacecraft-earth angle is small enough to allow suitable performance from the yet-to-be-deployed high gain antenna, communications are switched over to that antenna, and up to three additional trajectory correction maneuvers are conducted.

The orbit insertion phase begins with the Mars orbit insertion burn of the spacecraft's main engine and concludes when the spacecraft is in the desired mapping orbit. The most significant activity during this phase is the aerobraking operations that transition the orbit from the initial elliptical orbit to the circular mapping orbit.

Description of Aerobraking (from MGS Mission Plan, Project Document 542-405)

Aerobraking begins with an aerobrake walk-in maneuver (AB1). This propulsion system burn will lower the periapsis to an altitude of 138 kilometers and correct for slight inclination errors incurred during the orbit insertion burn. Currently, AB1 is scheduled to occur at the fourth apoapsis passage after Mars orbit insertion. Under normal circumstances, MOI will place the spacecraft into a highly elliptical, 48 hour period capture orbit at a descending node orientation of approximately 5:45 PM. Therefore AB1 will nominally occur nine days after MOI.

Aerobraking consists of three distinct sub-phases: walk-in, main phase, and walk-out. Walk-in represents the first of the three to occur and begin about nine days after MOI with the AB1 maneuver that lowers periapsis from the capture orbit periapsis altitude of 300 kilometers to 138 kilometers. Over the next month, three more walk-in maneuvers (AB2, AB3, and AB4) will gradually lower the periapsis to 112 kilometers and reduce the period to about 40.6 hours.

After completion of the walk-in, the spacecraft will spend three months in the main of aerobraking. During this period of time, repeated periapsis passages through the upper fringes of the Martian atmosphere will gradually slow the spacecraft and lower the apoapsis. By the end of the aerobrake main phase, atmospheric drag will have lowered the apoapsis from the original altitude of 57,000 kilometers down to about 2,000 kilometers.

The three weeks of aerobraking following the main phase represent an extremely critical period as the spacecraft lowers its apoapsis down to 450 kilometers. During that time, the spacecraft will slowly "walked-out" of the atmosphere by gradually raising its periapsis altitude to 143 kilometers. Daily aerobraking trim maneuvers (ABMs) will be performed as necessary to maintain a three day orbit lifetime. In other words, in the absence of ABMs due to unforeseen event that inhibit the ability of flight controllers to command the spacecraft, MGS will always be at least three days from a fiery crash.

Aerobraking will end with a termination maneuver (ABX) performed in late January 1998. This maneuver will raise the orbit periapsis out of the atmosphere, and to an altitude of approximately 400 kilometers. At this time, the spacecraft will be circling in a 400 x 450 kilometer orbit with a period slightly under two hours. In addition, the descending node location will have advanced from its original MOI position at 5:45 p.m. with respect to the fictitious mean Sun to nearly 2:00 p.m.

Following the aerobraking termination maneuver, the orbit is allowed to drift until the periapsis is at the south pole in February 1998 when a transition to mapping orbit burn is performed to freeze the mapping orbit. Gravity calibrations will be conducted, and the high gain antenna will be deployed before mapping operations begin.

Mapping will begin in March 1998 and last for one Martian year (687 Earth days). The spacecraft keeps the science instruments pointed at the planet surface, continuously collecting data. Once a day, this data is returned to the Earth during a 10 hour tracking pass.

The relay period (February 2000 to January 2003) follows mapping and consists of the use of the spacecraft's Mars Relay system to provide a Mars to Earth relay function for surface elements of future US missions and/or missions from other nations. During this period, a maneuver will raise the orbit to a near circular one of about 400 kilometers to assure that the probability that the unsterilized spacecraft would impact the planet meets the international requirements for planetary protection,

PAYLOAD DESCRIPTION

The MGS science payload is quite similar to that of Mars Observer. However, the lower launch mass of MGS as compared with Mars Observer (1350 kg vs. 2250 kg) required that only about half as much mass (75 kg vs. 150 kg) could be devoted to the science instruments. A committee of scientists appointed by NASA recommended the MGS payload which was subsequently approved. It consists of the MO payload minus the Pressure Modulator Infrared Radiometer (which has been selected to fly on the '98 Surveyor Orbiter) and the Gamma Ray Spectrometer (which is a candidate to fly on the '01 Surveyor Orbiter).

The MGS payload consists of the following instruments: Mars Orbiter Camera, Mars Orbiter Laser Altimeter, Thermal Emission Spectrometer, Magnetometer/Electron Reflector, and an Ultra Stable oscillator for Radio Science. A Mars Relay system is provided to relay information from surface elements to Earth.

The Mars Orbiter Camera consists of three cameras: two wide angle, and one narrow angle. The wide angle cameras, one with red response and one with blue response, are used for global images similar to those of terrestrial weather satellites with a resolution of about 7.5 kilometers. The narrow angle camera, with resolution of 2-3 meter, is used for studying specific surface locales and features. Each camera uses a line array CCD sensor, and produce their images in a "push broom" mode wherein the orbital motion of the spacecraft builds up the image line by line in the camera's large memory. The camera assembly is fixed to the spacecraft's nadir equipment deck. The wide angle cameras are attached to the forward edge of the narrow angle camera's telescope.

The Mars Orbiter Laser Altimeter measures the height of surface features by timing the return signal from laser pulses directed from the spacecraft to the Martian surface. The laser has a 160 meter foot print on the surface. By combining the laser return data with the spacecraft orbital position data, the height of surface features can be determined to a few tens of meters. The experiment will yield detailed topographic maps of Mars.

The Thermal Emission Spectrometer will be used to determine the properties of the Martian surface by measuring the infrared radiation emitted. Through the use of a scanning mirror, the instrument will also obtain data from the atmosphere.

The Magnetometer and Electron Reflectometer instruments will be used to search for evidence of a magnetic field and measure its strength, and to look for remnants of an ancient magnetic field. Its two magnetometer sensors are located at the tips of the outboard solar arrays. The electron reflectometer is mounted at the edge of the nadir equipment deck.

The radio science experiment is conducted with use of the spacecraft's telecommunications system. An ultra stable oscillator is included as part of the science payload to provide a very stable reference frequency for the spacecraft's transmitter. The experiment will make temperature and pressure profiles of the planet's atmosphere by observing the changes in this reference frequency as received by the Deep Space Network tracking stations as the spacecraft goes behind and emerges from behind the planet.

The Mars Relay system, provided to NASA by the French Space Agency, CNES, will be used to relay data from the Russian '96 mission's surface elements to Earth. This 400 MHz system stores its received data in the memory of the Mars Orbiter Camera before it is stored in the spacecraft's solid state recorders for transmission to Earth. The system will also be available after the MGS mapping mission is complete to relay data from the Surveyor '98 lander. The system uses a downlink beacon to activate transmission of relay data, but essentially provides only a one way communication link from the surface to the MGS spacecraft.

Data are formed into packets within the instruments. The packets are routed through the spacecraft's command and data handling system transmitted to the Earth, routed through the ground data system and the Principal Investigators' operations centers where they are processed into the experiment products.

The MGS mission also includes six investigations conducted by a group of Interdisciplinary Scientists who will use data from previously described investigations to form a fuller picture of Mars as a global entity. These investigations include: weathering, geosciences, polar atmospheric science, surface-atmospheric science, climatology, and surface properties and geomorphology.

Science products from MGS will be rapidly deposited in the various nodes of the NASA Planetary System for distribution to the worldwide science community. In addition, the data will be archived in the National

Science Data Center for access by the general public. Images and other science data will be released to the public media in near-real-time as soon as the necessary processing and calibration has been completed.

SPACECRAFT DESCRIPTION

The MGS spacecraft is designed to carry the science payload to Mars, maintain its proper pointing and orbital conditions, and to return the acquired data to Earth. The spacecraft's mapping configuration is shown in Figure 1.

The spacecraft's electronic architecture is based on that of Mars Observer. Most of the major electronic assemblies are spare Mars Observer units that have been retrofitted to eliminate post-MO identified discrepancies. The design is generally single fault tolerant with redundancy managed by the spacecraft's central computers.

The spacecraft consists of two mated mechanical modules: the equipment module that contains most of the spacecraft's electronics, and the propulsion module that contains all the propulsion components, fuel and pressurant tanks, and the spacecraft's batteries. The science payload, except for the two magnetometer sensors, are located on the nadir equipment deck atop the electronics module.

The X band telecommunications system consists of the two Mars observer transponders, the MO high gain antenna reflector with a modified RF feed, two new Thompson 25 watt traveling wave tube power amplifiers and a new set of low gain antennas. A Ka-band engineering experiment is included. The transponders are in the main bus structure, the power amplifiers, and the Ka-band electronics are located in an enclosure on the back of the two axis articulated high gain antenna. The high gain antenna and its two axis gimbals are deployed on a short boom in order to provide a clear view of Earth during orbital operations. Command rates vary from 7.8125 bps to 500 bps, with 125 bps being the nominal rate.

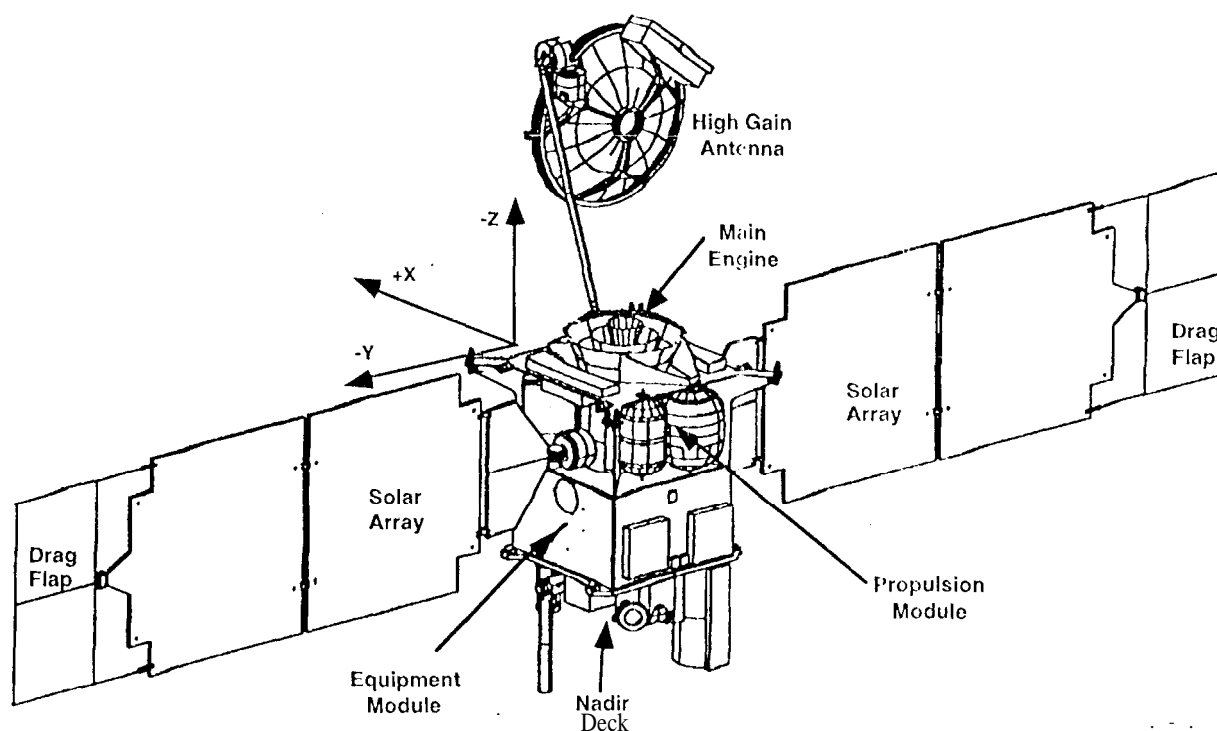
The spacecraft's direct conversion electrical power system uses four solar panels in two wings to generate power for operating the spacecraft and charging two 20 A-hr nickel hydrogen batteries. The area of the solar arrays was chosen to provide the necessary area for aerodynamic drag within the

heating constraint of 0.38 W/m^2 . Part of the arrays are implemented with Ga Ar cells (inner panel), and part with Si cells (outer panel) to achieve the required power capability of 940 watts at perihelion and 660 watts at aphelion. Spacecraft loads are switched by the command and data handling subsystem and are

centrally fused. The power supply electronics and battery charge assemblies are spare MO hardware.

The command and data handling system consists entirely of spare MO hardware with the exception of two new solid state recorders (1.5 Gbits each) that replace the three MO tape recorders. Software

Figure 1: MGS Spacecraft Mapping Configuration



resides in the redundant Standard Controls Processors (128K words RAM, 20K words PROM) (one operated in the hot backup mode), in the Engineering Data Formatter, and the in the Payload Data Subsystem. This system decodes ground commands, sequences the spacecraft events, provides fault protection, payload instrument control, data formatting and data storage. Telemetry rates vary from 10 bps to 85 kbps.

A dual mode propulsion system, newly designed for MGS with significant heritage from the Cassini spacecraft's propulsion design, provides for

momentum unload, control torques, anti spacecraft velocity change. A single 596 N bi-propellant engine provides the thrust for Mars orbit insertion. Twelve 4.45 N monopropellant thrusters provide for momentum unloading, low delta velocity maneuvers, and thrust vector control. Significant care has been taken to avoid the potential problems of propellant vapor mixing that has been suggested to be the cause of the failure of Mars Observer.

Three axis attitude control is provided through a series of sun sensors, a celestial sensor assembly, an inertial reference unit, a Mars horizon sensor, and four

reaction wheels. Attitude control software resides in the spacecraft's command and data handling system.

Thermal control is provided with blankets, surface treatments and electrical heaters.

The equipment module and the propulsion module are constructed with composite surface sheets on aluminum honeycomb and are edge clamped without supporting frames,

The spacecraft mass is summarized in table II:

TABLE II: SPACECRAFT MASS SUMMARY

Payload:	75 kg
Spacecraft bus:	590 kg
Fuel:	385 kg
Launch mass:	1,050 kg

Major technical parameters and capabilities of the spacecraft are listed in Table III:

TABLE III: SPACECRAFT CHARACTERISTICS

Transmitter power:	25 watts
Downlink frequency:	X-band
Downlink Data Rates:	10 bps - 85 kbps
Uplink frequency:	X-band
Uplink Data Rates:	7.81 - 25-500 bps
Attitude control system:	Three-axis stable
Attitude stability:	1 mrad (for 0.5 s) 3 mrad (for 12 s)
Attitude control:	10 mrad
Attitude knowledge:	3 mrad
Data storage capacity:	3 Gbits

The spacecraft flies with the solar arrays canted 30° toward the +Z axis and the acro flow towards the main engine side of the propulsion module during aerobraking. This provides a dynamically stable configuration where the center of pressure is behind the center of mass. The projected area of the spacecraft is about 17 m² and the ballistic number is 22.4 kg/m².

FLIGHT OPERATIONS

Flight operations for MGS will be managed and conducted by the Surveyor Flight Operations Project. This operation team will eventually be able to conduct

the flight operations of all the Surveyor spacecraft (MGS, '98 orbiter, and the '98 lander, and future missions) simultaneously.

Basic elements of the flight operations consist of navigation (orbit determination and maneuver design), spacecraft health and welfare, ground data system (operations and development), mission and sequence planning, and real-time management and control.

Surveyor flight operations are characterized by remote (from JPL) control of the science instruments and the remote operations of the spacecraft. The science instrument operation control and science instrument data processing are conducted at the home institutions of the instruments principal investigators or team leaders. The spacecraft health and welfare operations are conducted by the Project's industrial partner, Lockheed Martin Astronautics, at its Denver, Colorado facility where the spacecraft is built and tested. Data circuits provided by the NASA ground communications facility provide connectivity between remote sites and JPL, where tracking data is received from the Deep Space Network and stored, and where command messages for the spacecraft are assembled.

JPL performs mission management, navigation, data administration, and mission planning and sequence development in Pasadena.

Except for periods of critical activities (launch, trajectory correction maneuvers, Mars Orbit Insertion and aerobraking), operations are conducted during regular business hours, five days per week.

The ground data system provides software and workstations for spacecraft system test, spacecraft flight operations, science instrument operations, navigation, data processing and archiving, and the project data base.

EDUCATION AND OUTREACH

MGS, in cooperation with the other current NASA Mars missions, is conducting a vigorous program of public and educational outreach, designed to further distribute information about and from the project for educational advancement. Using MGS data as a catalyst, educational materials will be developed and distributed with emphasis on grades K-12. Outreach

centers at universities around the continental U.S., Alaska and Hawaii are focal points for regional distribution, CD-ROM based teaching materials are being developed, as are video and hard copy teaching material using Mars and the MGS mission as tools for improving education in science and mathematics.

DEVELOPMENT STATUS THIRTEEN MONTHS BEFORE LAUNCH

As of 1 October 1995, a little more than 13 months before the opening of the launch period, the MGS project is on schedule and operating within its cost plan. All of the major system and subsystem level design reviews have been satisfactorily completed. Reserves of approximately 34% remain on the cost to complete the pre-launch development. Fifty-five days of funded slack time exist in the critical path activities to launch.

The spacecraft is being assembled at Lockheed Martin Astronautics in Denver, and the first application of electrical power to the command and data handling system installed on the spacecraft structure is anticipated in mid-October.

The Ultra Stable Oscillator for the science payload has been delivered on schedule. The Mars Orbital Camera and the Mars Relay are scheduled for delivery to the spacecraft on 1 November, with the Magnetometer/Electron Reflectometer expected on 1 December. The Mars orbiter Laser Altimeter and the Thermal Emission Spectrometer are in assembly and test at this date, and are expected to join the spacecraft on 1 March and 1 April 1996, respectively.

The ground data system that supports spacecraft system testing and flight operations has been delivered.

While the MGS mission operations system has been designed to operate in a standalone manner providing service to only the MGS mission, the development of the multi-spacecraft Surveyor Flight Operations Project is in its definition (phase B) phase. A critical design review of the multi-spacecraft operations plan will be conducted in February 1996, and the MGS flight operations will be spun-off from the basis of the Surveyor Flight Operations Project in March 1996.

MARS OBSERVER LESSONS

The Mars Observer experience has been extremely valuable in the programmatic and technical execution of the MGS project. Carrying forward these lessons has been facilitated because the core management team at JPL have direct MO experience.

From a programmatic standpoint, the recognition of the importance of the cost driven paradigm and the sensitivity to the issues of performance growth that were dominant in the MO development have been one of the most important lessons. Equally important has been the establishment of programmatic metrics that were not used on MO.

In the technical area, the use of MO spare hardware and software allowed the collection of previously undetected design faults that may have impaired MO operation in orbit. The use of the mission design, ground data system and the improvements therein suggested by the MO mission as flown, have proven to be large cost saving. The thermal design lessons of the pressurant portion of the propulsion subsystem have been carefully applied. The benchmark of the MO flight operations experience has enabled a 40% reduction in the operations staffing with the addition of several automated flight operations management and analysis tools. And finally, the application of strong system engineering at the project level, that did not exist during the MO development, has been a key enabling capability in making design decisions faster and in a better manner.

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